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TECHNICAL REPORT

HIGH STRENGTH ALUMINUM CASTING ALLOYS

By

R. B. Miclot

Department of the Army Project No. -

AMC Code No. 4230.15.6016.30.01

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Laboratory Director

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Rock Island Arsenal
Rock Island, Illinois

ABSTRACT

The results of tensile tests on three types of high-purity cast aluminum alloys are presented. Alloy A (zinc-magnesium-chromium type), when heat treated in 3-inch casting thickness, exhibits approximately 48,000 psi. yield strength, 55,000 psi. tensile strength, and 8% elongation. These minimum values are also observed 5-1/2 inches from a chilled end of a heat treated, 1-inch thick, cast plate. C355 alloy (silicon-copper-magnesium type) ranks second in yield and tensile strengths, attaining 80 to 85% of the Alloy A strength levels. Alloy A356 (silicon-magnesium type) ranked third.

CONCLUSIONS

1. Of the three types of high-purity aluminum alloys investigated:

a. Alloy A (zinc-magnesium-chromium type) produces the highest yield and tensile strengths and elongation in any comparable casting section.

b. C355 (silicon-copper-magnesium type) ranks second in yield and tensile strengths, attaining 80 to 85% of the Alloy A strength levels.

2. Drastic chilling of thick cast sections of these alloys greatly improves tensile strength and elongation, but does not appreciably alter the yield strength.

3. Yield strength is not severely impaired in cast sections properly fed even though remote from a chilled surface.

4. The end-chilled plate test provides a comparatively simple means to evaluate the mechanical properties of high strength alloys.

RECOMMENDATIONS

The following measures are recommended:

1. Incorporate these high strength alloys in redesigned, light weight, cast aluminum components.

2. Evaluate the toughness quality of these alloys in terms of impact strength or shock resistance.

3. Investigate simple heat treat methods to develop greater mechanical strength than presently obtained in either thin or thick sections of castings.

4. Determine the tensile and impact efficiency of these high strength materials in the heat affected zones of weldments without post heat treatment.

HIGH STRENGTH ALUMINUM CASTING ALLOYS

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HIGH STRENGTH ALUMINUM CASTING ALLOYS

OBJECT

The objective of this investigation is to evaluate three high strength aluminum alloys by comparison of tensile properties of specimens cut from heat treated castings.

INTRODUCTION

Marked improvement in mechanical properties of sand-cast aluminum alloys has been achieved in recent years. Some of these alloys are capable of developing high yield strength-to-weight ratios with good ductility. This feature is a contribution toward filling the Army's need for flexible mobility and is valuable to the designer interested in weight reduction of Army weapons components for field and airborne units.

Knowledge of what strength may be expected in thick cast sections is also important to a designer. Boss sections, trunnions, intersections, and other thick portions in critical areas can be difficult to produce to high strength requirements. Three interdependent factors are essential for achievement of optimum properties in any section: (1) High-purity, heat treatable alloy; (2) proper foundry technique for specific casting design; and (3) adequate heat treatment.

An attempt has been made to evaluate three high-purity alloys in the terms of mechanical properties obtained directly from casting sections, rather than from separately cast test-size tensile bars.

Three types of commercially available aluminum alloys of low impurity content were selected for the investigation. Their analyses are shown in Table I.

TABLE I

INGOT COMPOSITION, %

	Alloy		
	C355	Alloy A	A356
Copper	1.0	.01	.01
Iron	.12	.05	.11
Silicon	4.9	.04	6.9
Manganese	-	.04	-
Magnesium	.54	.68	.32
Zinc	-	6.6	-
Chromium	-	.10	-
Titanium	.12	.19	.14

PROCEDURE

Test Casting Designs. Two principal test designs were employed throughout the investigation. The step portion of the block, shown in Figure 1, was made in the drag section of the mold. Cope ingates were located near the joint of the 1-inch and 2-inch thick sections. A top riser was positioned along the joint of the 2-inch and 3-inch sections. The plate, shown in Figure 2, had a cope ingate across an end, above which was placed a top riser. An aluminum chill formed the vertical surface at the opposite end. Separate cast-to-size tensile bars were also poured from each alloy melt. The 4-bar test mold design, shown in Figure 3, involved a gating system modification of the pattern described in Federal Specification QQ-M-56.

Sand. All molds were prepared by hand-ramming, using an oil green sand mix. A formulated bonding agent, Petro Bond, was used to bond a washed and dried silica sand, A.F.S. Grain Fineness No. 140, with petroleum oil. The green properties after mulling were:

Compression strength, psi. - 11

Permeability, cc. per min. - 7.5

Chills. Uncoated, unscored aluminum blocks (indicated in Figures 1 and 2) were applied in the drag section of certain stepblock molds and cope sections of each plate mold. Table II shows the chill weight ratios employed.

TABLE II

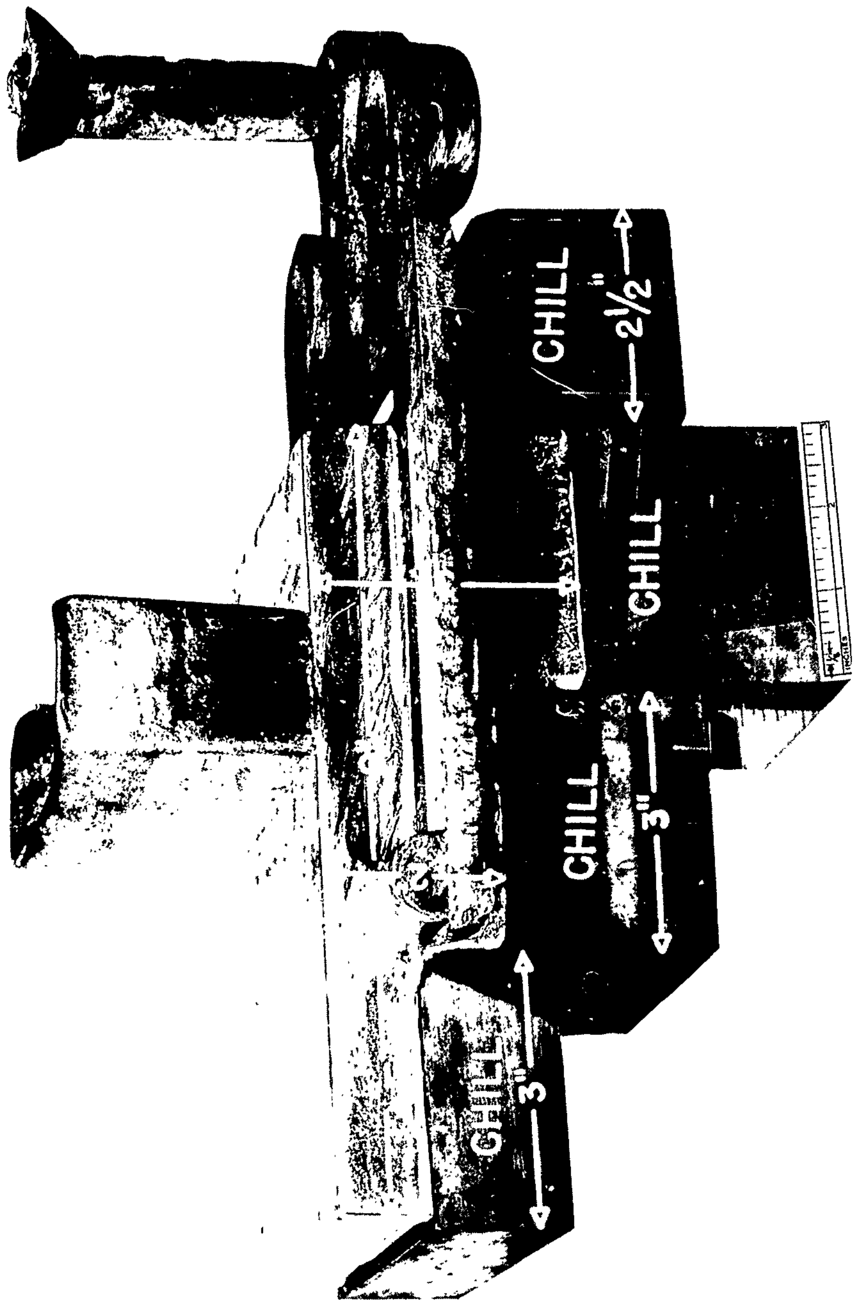
CHILL WEIGHT RATIOS

Chill Weight-To-Stepblock Casting Weight = 1.5

Chill Weight-To-Plate Casting Weight = 1.5

Chill Weight-To-Chilled Stepblock Surface Area = 0.24 psi.

Chill Weight-To-Chilled Plate Surface Area = 1.4 psi.



STEPBLOCK TEST CASTING WITH ASSEMBLED CHILLS

FIGURE 1

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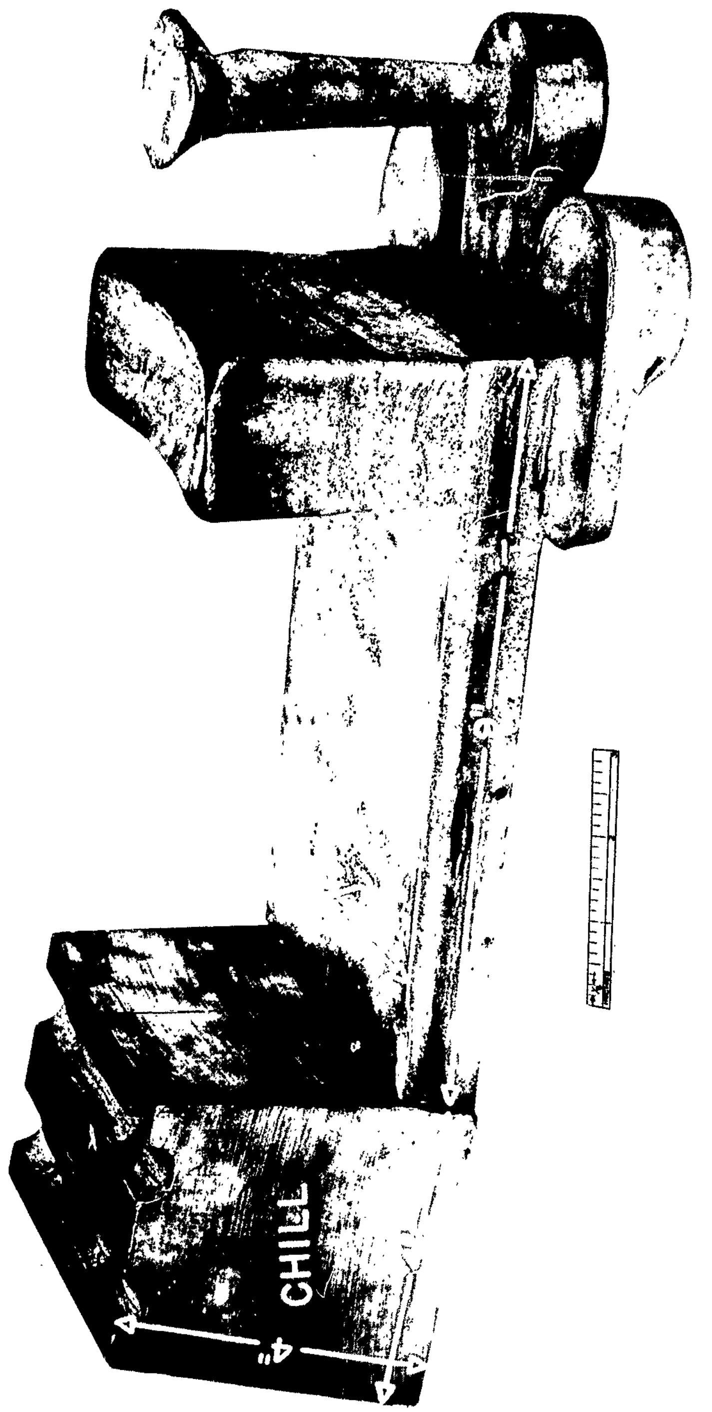

TEST PLATE CASTING WITH CHILL AT END

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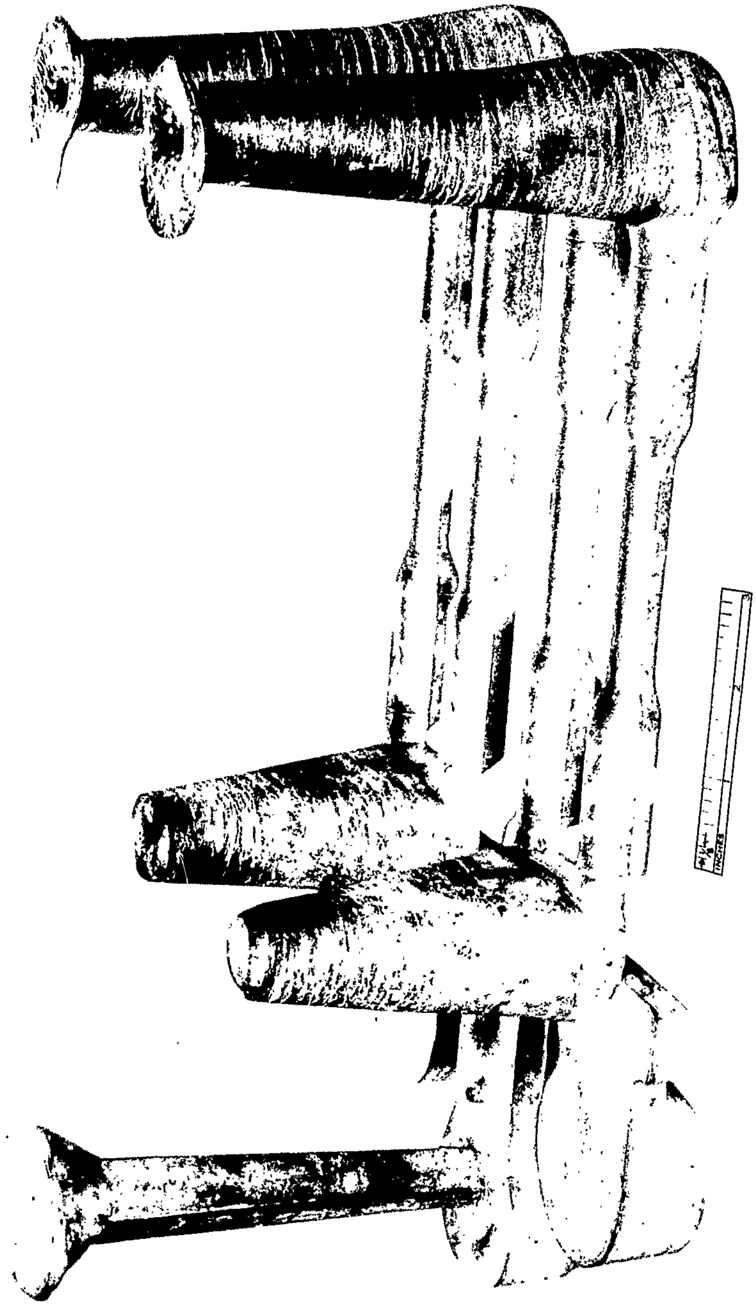

TEST BAR CASTING SHOWING CAST-TO-SIZE TENSILE SPECIMENS

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Melting. Each alloy was purchased in ingot form and was melted in a 50 K.W., 3000 cycle induction lift-coil unit. Degassing was accomplished with a 90% nitrogen, 10% chlorine gas mixture evolving approximately 2/3 cu. ft. per 40 lb. melt.

The gas proportioning equipment and closed-end, radial-hole carbon lance used in degassing appear in Figure 4. Manual control valves permit correct proportioning, and flow-meters measure the flow rate of each gas to the mixing "T".

The pouring temperatures used are given in Table III.

TABLE III

POURING TEMPERATURES

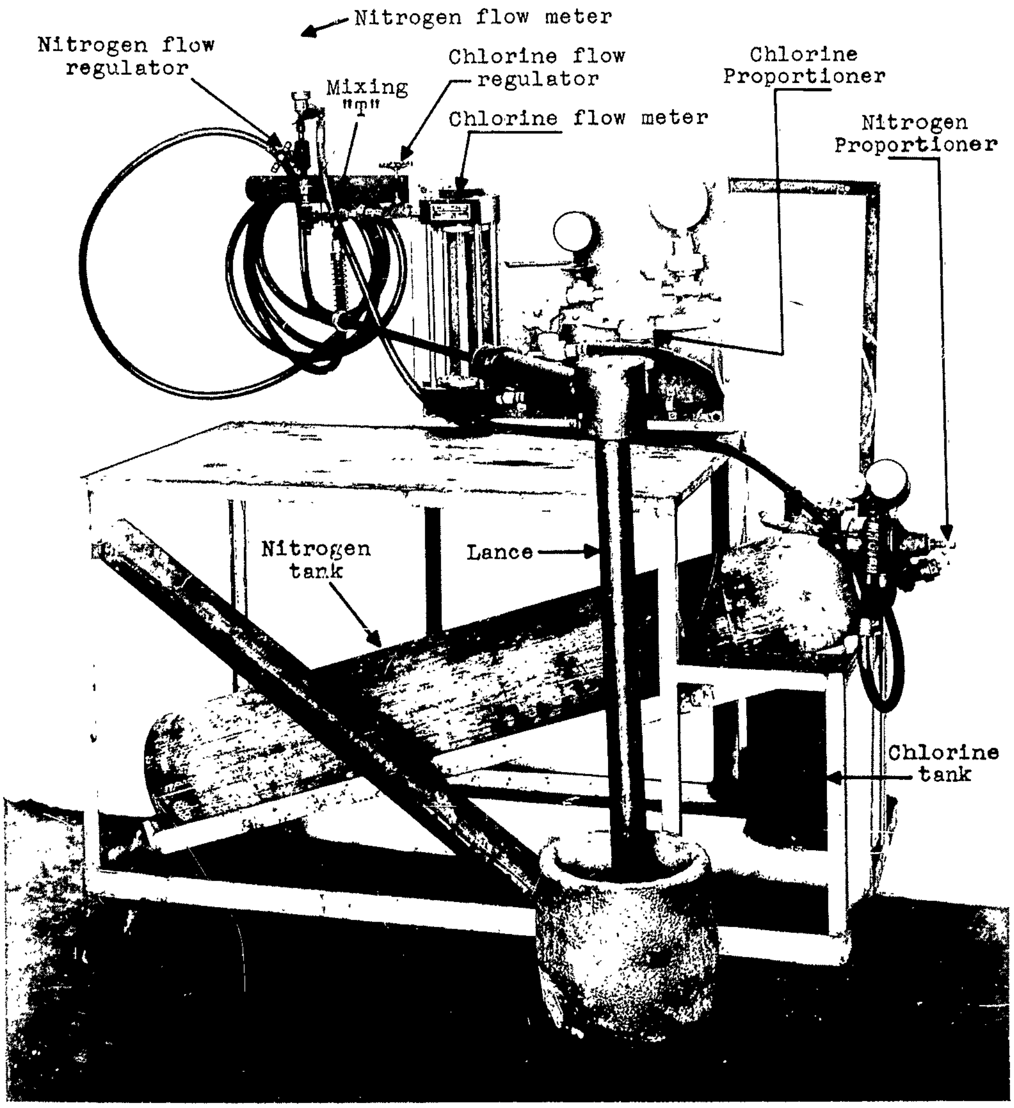
	Alloy		
	C355	Alloy A	A356
Pour Temp., °F.	1325	1430	1350

Heat Treatment. The heat treating procedures employed for the castings are in general accord with the suppliers' recommendations and are presented in Table IV.

TABLE IV

HEAT TREATING PROCEDURES

	Alloy		
	C355	Alloy A	A356
Solution Treatment	24 hours @980°F, W.Q.	12 hours @1100°F, W.Q.	15 hours @1000°F, W.Q.
Quench Water Temperature	158°F	184°F	150°F
Precipitation Treatment	12 hours @310°F	15 hours @285°F	9 hours @310°F



NITROGEN-CHLORINE DEGASSING APPARATUS

FIGURE 4

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Testing. Type R-1 tension specimens (Federal Test Method 151) were machined out of blanks removed from the stepblocks and plates. Blank locations in the stepblocks are shown in Figure 5 and referred to in Tables VI, VII, and VIII. Yield strengths were determined by the extension-under-load method using a 0.2% offset.

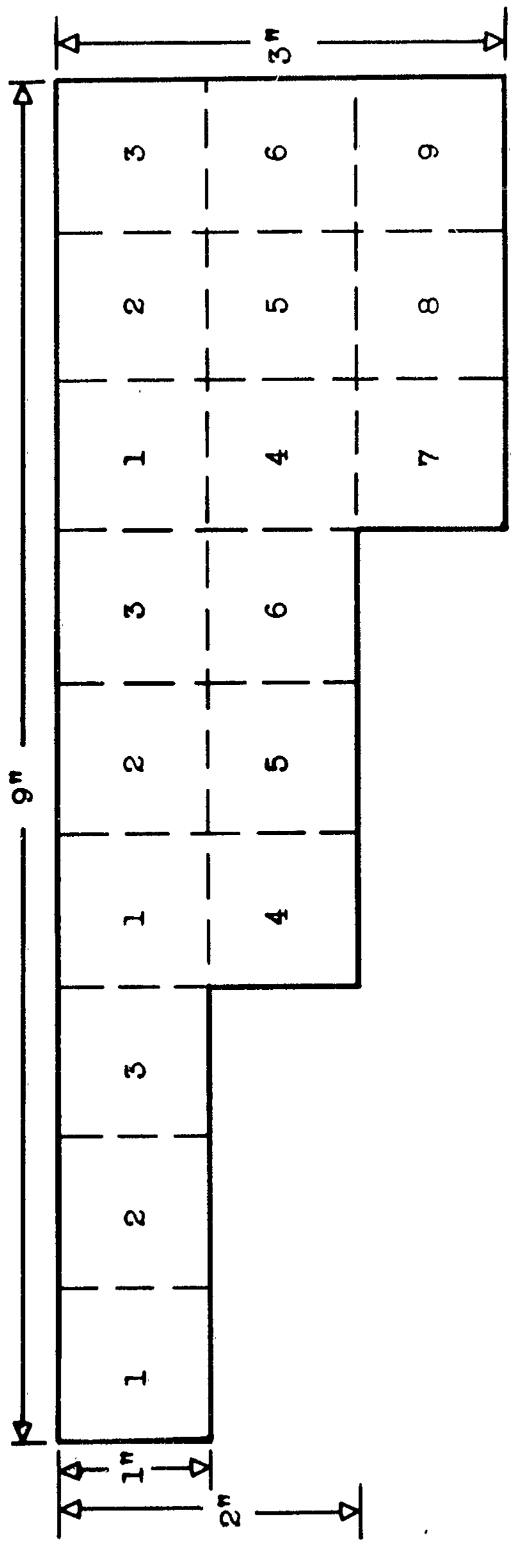
RESULTS

Spectrographic analyses of the degassed and cast alloy heats appear in Table V. Tensile results from the stepblocks are listed in Tables VI, VII, and VIII. The mechanical values obtained from the end-chilled cast plates are enumerated in Table IX for each alloy and quantitatively presented in Figure 6. Table X is a rearrangement of the data appearing in Tables VI, VII, and VIII. Table XI is included to show mechanical test results from separate, cast-to-size tensile bars from the alloy heats. Strength-to-weight comparisons of the investigated alloys with other cast materials are given in Table XII.

TABLE V

SPECTROGRAPHIC ANALYSES OF MELTS

	Alloy		
	C355	Alloy A	A356
Copper	1.0%	.01%	$<$.01%
Iron	.15	.06	.08
Silicon	4.9	.06	6.9
Manganese	$<$.01	.05	.02
Magnesium	.61	.86	.48
Zinc	.03	6.6	.01
Chromium	Trace	.10	Nil
Titanium	.10	.16	.10



END VIEW OF SPECIMEN BLANK LOCATIONS IN STEPBLOCKS

FIGURE 5

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TABLE VI

MECHANICAL PROPERTIES OF C355 STEPBLOCKS

Unchilled					Chilled		
Y.S. psi.	U.T.S. psi.	E. %	Section Thick- ness, in.	Position see (Fig. 5)	Y.S. psi.	U.T.S. psi.	E. %
38300	42100	1.1	1	1	37900	49300	3.6
37800	38400	1.0	2	2	38500	46800	2.5
-	-	-	2	3	39500	47400	1.9
37500	39300	.7	2	5	39300	48000	2.1
-	-	-	3	1	39500	47500	1.9
33700	33700	.8	3	5	41000	48500	1.9
36400	37200	1.2	3	9	38500	51900	5.0

TABLE VII

MECHANICAL PROPERTIES OF ALLOY A STEPBLOCKS

Unchilled					Chilled		
Y.S. psi.	U.T.S. psi.	E. %	Section Thick- ness, in.	Position see (Fig. 5)	Y.S. psi.	U.T.S. psi.	E. %
50000	56900	3.9	1	1	48900	58100	10.8
-	-	-	2	2	47400	54300	10.0
-	-	-	2	3	46100	52500	10.6
-	-	-	2	5	49300	57600	10.2
-	-	-	3	1	46600	53600	9.2
-	-	-	3	5	48500	55200	9.8
25100	25800	1.2	3	9	48200	56200	8.1

TABLE VIII

MECHANICAL PROPERTIES OF A356 STEPBLOCKS

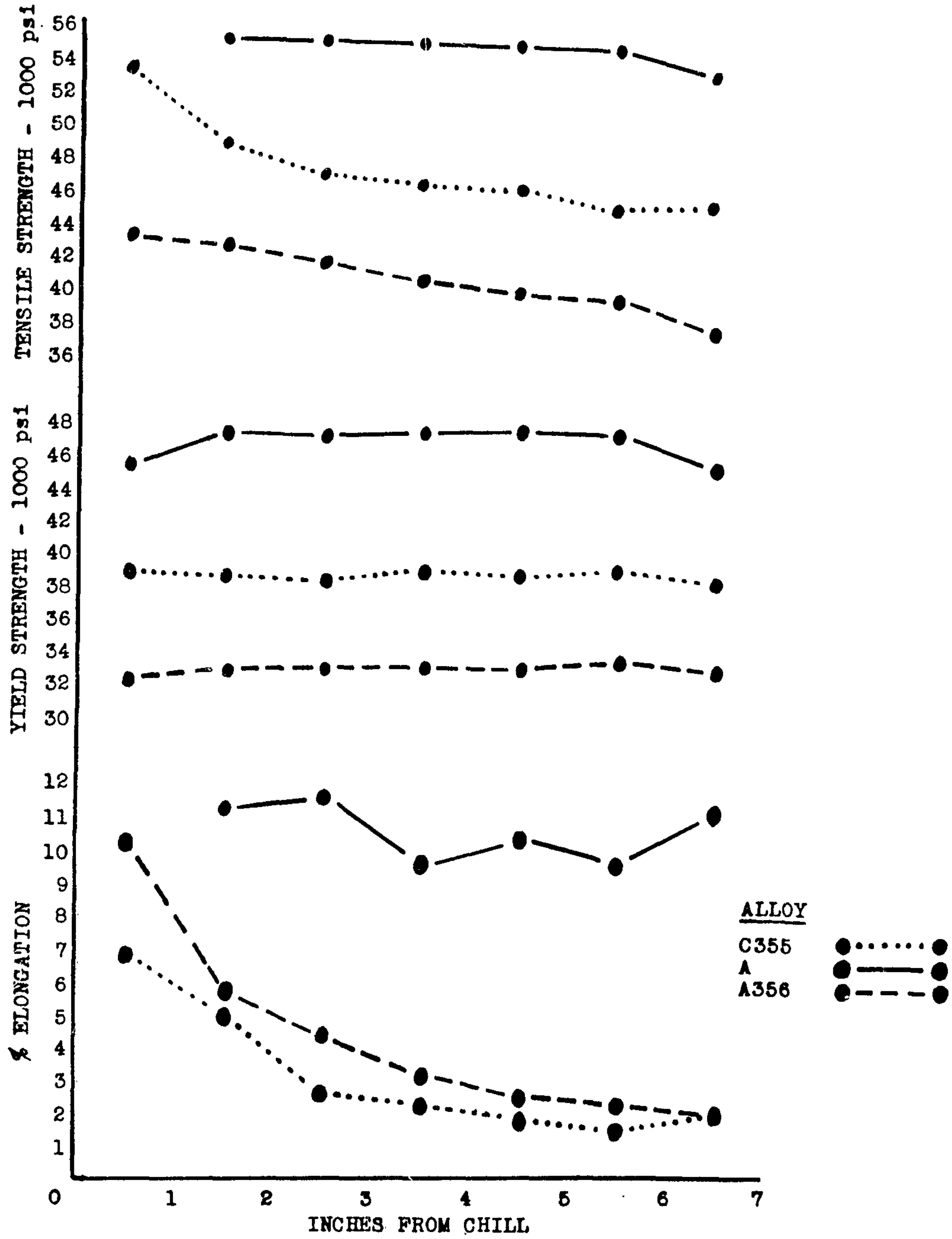
Unchilled			Section Thick-ness, in.	Position see (Fig. 5)	Chilled		
Y.S. psi.	U.T.S. psi.	E. %			Y.S. psi.	U.T.S. psi.	E. %
35000	37200	1.0	1	1	-	-	-
-	-	-	1	2	35200	40000	1.7
-	-	-	2	2	35000	42100	4.0
-	-	-	2	3	35400	43400	4.0
33000	33000	.7	2	5	36200	42800	2.7
-	-	-	3	1	35200	43000	3.7
-	-	-	3	5	36300	44500	4.9
-	-	-	3	8	36100	44500	4.4
29100	29100	.6	3	9	-	-	-

TABLE IX

MECHANICAL PROPERTIES OF END-CHILLED 1-INCH THICK PLATES

Inches From Chill	C355 Alloy			Alloy A			A356 Alloy		
	Y.S. psi.	U.T.S. psi.	E.%	Y.S. psi.	U.T.S. psi.	E. %	Y.S. psi.	U.T.S. psi.	E.%
1/2	38800	53700	6.9	45600	53700	6.4*	32200	43200	10.3
1-1/2	38500	48800	4.0	47700	55400	11.2	33000	42300	5.8
2-1/2	38200	47000	2.6	47600	55200	11.6	33100	41900	4.5
3-1/2	39100	46200	2.2	47700	55200	9.5	33200	40600	3.1
4-1/2	38600	46000	1.7	47700	54900	10.3	33200	39900	2.6
5-1/2	39000	45000	1.5	47500	54400	9.6	33600	39300	2.2
6-1/2	38000	45200	2.0	45100	53100	11.1	32700	37500	2.0

*Small flaw caused low tensile and elongation.



MECHANICAL PROPERTIES OF C355, ALLOY A, AND A356
H' PURITY ALUMINUM ALLOYS. ONE-INCH THICK PLATE
'GS. SOLUTION AND PRECIPITATION HEAT TREATMENT

FIGURE 6

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TABLE X

DATA FROM TABLES VI, VII, AND VIII
(Strength in 1000 psi.)

Section Thick-ness, in.	Specimen Location	C355 Alloy			Alloy A			A356 Alloy		
		Y.S.	U.T.S.	E.%	Y.S.	U.T.S.	E. %	Y.S.	U.T.S.	E.%
3	Adjacent to chill	38.5	51.9	5.0	48.2	56.2	8.1	36.1	44.5	4.4
3	Between chill and riser	41.0	48.5	1.9	48.5	55.2	9.8	36.3	44.5	4.9
3	Adjacent to riser	39.5	47.5	1.9	46.6	53.6	9.2	35.2	43.0	3.7
2	Adjacent to chill	39.3	48.0	2.1	49.3	57.6	10.2	36.2	42.8	2.7
2	Between chill and riser	38.5	46.8	2.5	47.4	54.3	10.0	35.0	42.1	4.0
2	Adjacent to riser	39.5	47.4	1.9	46.1	52.5	10.6	35.4	43.4	4.0

TABLE XI

MECHANICAL PROPERTIES OF CAST-TO-SIZE
(1/2-IN. DIAM.) TENSILE SPECIMENS

	C355 Alloy	Alloy A	A356 Alloy
Yield Strength, psi.	42200	48800	35600
Ultimate Tensile Strength, psi.	55600	56800	41600
Elongation, %	5.1	4.8	3.1

DISCUSSION

Various arrangements of the gates and riser on the step-block were tried in order to improve soundness in each section without chilling. The adopted arrangement was based upon the apparent soundness developed in deep-etched sections of the C355 alloy. However, considerable microshrinkage occurred in the unchilled stepblocks of each alloy. Severe shrinkage, particularly near the riser, was observed in the unchilled block of the Alloy A. Chilling produced much smaller and fewer voids in the stepblocks of each alloy.

Examination of Table VI shows that the yield strength was not greatly variant in the thick or thin, chilled or unchilled sections. Chilling had effected a tensile strength increase of approximately 17% in the 1-inch thick section and 40% in the 3-inch portion of the C355 alloy. Greater improvement is shown in the elongation property of the chilled, thick part of the block compared to the 1-inch thick section.

Superior mechanical values obtained in the thickest section are attributed to gate and riser locations with respect to the chills.

From Table VII it is apparent that chilling had a profound effect in achieving high mechanical strength in each section of the Alloy A block.

The data presented in Table VIII show that slightly better tensile and elongation values were obtained in the thickest portions of the chilled A356 block.

The mechanical strength data appearing in Table IX and plotted in Figure 6 illustrate significant comparisons of the alloys. Yield strength values vary only slightly for each alloy at successive distances from the end chill. The combined mechanical properties of Alloy A are superior to the other two alloys and remain fairly uniform at any distance from the chilled surface of the 1-inch thick plate.

Correlation exists between the tests obtained from the stepblocks and end-chilled plates. The property curves shown in Figure 6 illustrate the trend of values also observed in the 3-inch sections of the blocks. (Compare with Table X). The 2-inch sections do not conform as closely to this tendency because of the gate-riser-chill arrangement.

Yield strength values of the separately cast tensile bars, shown in Table XI, were higher than any obtained from the end-chilled plates and chilled stepblocks of the respective alloys.

The aluminum alloys investigated produced high yield strength-to-density ratios. (See Table XII). Favorable values appear when comparison is made with some other metallic cast materials listed in the literature.

TABLE XII

COMPARISON OF SEVERAL FERROUS AND NONFERROUS CAST MATERIALS

Alloy	Yield Strength, psi.	Density, Lbs./ Cu. In.	Yield Strength/ Density
Magnesium, AZ63A	19,000 (typical)	.066	290,000
Magnesium, AZ92A	22,000 (typical)	.066	330,000
Aluminum, A356	36,000	.097	370,000
Aluminum, C355	38,000	.098	388,000
Nodular Iron (heat treated to 302 Brinell)	100,000	.257	390,000
Steel, .30% Carbon, Alloy (heat treated to 302 Brinell)	125,000	.283	440,000
Aluminum, Alloy A	47,000	.102	460,000

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